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Site Index Curves for Aspen in the Central Rocky Mountains

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Site index curves for aspen stands in the central Rocky Mountains were developed from one-time measurements of height and age of dominant trees. These curves are compatible with site tree data collected in forest inventories. Nonlinear equations, a figure, and two tables for estimating site index or height are presented.

Keywords: *Populus tremuloides*, site index, site quality

Introduction

Forest site quality and productive capacity usually are measured by site index. Previously published site index curves for aspen (*Populus tremuloides* Michx.) in Colorado were based on stem analysis measurements from three selected dominant trees on each of 59 plots that indicated height and age of the plot at different periods in time (Jones 1966, 1967).

Trees selected for stem analysis should be free of injuries which inhibit height growth. These factors are noticeable when stems are dissected for stem analysis; but, it may not be possible to detect such injuries when selecting trees during forest inventories for comparison to site index curves. Because only one-time measurements of height and age are obtained during most forest inventories, more consistent results may be expected if the trees used to derive the curves and those measured later to estimate site index are both sampled in the same manner from populations of trees as they exist in the forest (Brickell 1968). Nondestructive measurements also allow a larger sample collected over a greater range of stand conditions and physiographic factors to be used in developing site index curves.

This research note presents site index curves for aspen stands in Colorado, southern Wyoming, and northeastern Utah which are compatible with forest inventory procedures. The curves are based on nondestructive, one-time measurements of dominant tree height and age at breast height (4.5 feet above groundline on the uphill side of the tree) needed to classify aspen stands. The curves are based on a simple nonlinear equation for use with pocket calculators or computers.

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Methods

Two independent studies conducted in aspen stands in the central Rocky Mountains provided height and age measurements used to construct the site index curves. As part of a stand growth study, 105 temporary fixed area plots were established. Fixed plot area was varied, depending on stand density, to include 100 to 150 trees. A stand classification study provided an additional 117 variable radius plots sampled with a basal area factor of 10 or 20 square feet per acre and 23 fixed area plots containing 20 to 30 trees. Location of the 245 plots by National Forest is summarized in table 1. To minimize within-plot variability, plots were established within a single clone, as determined by branching, bark, stem form, and spatial characteristics. Each plot was on an area of homogeneous site quality, selected on the basis of physiographic, surface soil, and tree conditions. On each plot, three to five even-aged dominant trees with no apparent height growth inhibiting injuries or diseases were measured for total height to the nearest foot; age at breast height was determined in the field using increment cores. Allowable ranges in tree ages within a plot to be classified as even-aged were 5 years for trees up to 50 years of breast height age, 10 years for trees 51 to 100 years, and 20 years for trees older than 100 years. If enough suitable trees were not available within the plot, additional trees adjacent to the plot on the same apparent site were measured. The plots were regarded as independent observations in the analysis, and an average dominant height and breast height age was calculated for each plot. Average dominant height ranged

Table 1.—Location and number of temporary plots used to construct site index curves for aspen.

National Forest	Growth study	Classification study	Total
Arapaho	0	12	12
Grand Mesa	0	4	4
Gunnison	4	14	18
Pike	0	7	7
Rio Grande	9	19	28
Roosevelt	7	8	15
Routt	7	12	19
San Isabel	0	9	9
San Juan	24	21	45
Uncompahgre	5	19	24
White River	28	11	39
Medicine Bow	12	4	16
Uinta	1	0	1
Wasatch	8	0	8

from 15.5 to 128.0 feet; and breast height age ranged from 9.7 to 191.7 years.

The average height-age data were sorted by ascending age and were separated into groups so that each group contained about 10 observations without breaking up groups of observations of the same age. Twenty-two groups resulted with 9 to 14 observations, except for the highest age group which contained only 4 observations. The average height of each group was plotted over its corresponding average age. A common origin at breast height for height, age, and site index was obtained by subtracting 4.5 feet. Nonlinear least squares methods were used to fit various mathematical models to the grouped data to obtain a guide average height-age curve. The models examined were:

1. $H-4.5=b_1(1-b_2e^{b_3A})^{b_4}$ (Richards 1959)
2. $H-4.5=b_1+b_2e^{b_3A}$ (Grosenbaugh 1965)
3. $H-4.5=A^2/(b_0+b_1A+b_2A^2)$ (Prodan 1968)
4. $H-4.5=e^{b_0+b_1A^{-1}+b_2A^{-2}+b_3A^{-3}+b_4A^{-4}}$ (Farrar 1981)

where: H = average dominant height (feet).
A = average breast height age (years).
e = base of natural logarithms.
b_i's = constant parameters of the model.

Using computed coefficients of determination (R^2) as measures of goodness of fit, model 1 resulted in a 2.8% to 6.4% improvement in fit to the average height-age data relative to the other models. In addition, a plot of the curve on the height-age data showed it was satisfactory over the entire age range. In fitting model 1, the estimate of b_2 was very close to 1; therefore, that parameter was subsequently dropped from the model. The final guide curve equation was

$$H-4.5=119.25\,(1-e^{-0.007719A})^{0.93972}$$
$$R^2=0.917\quad s_{y.x}=5.19.$$

In the central Rocky Mountains, aspen lives much longer and grows more slowly than in the Lake States. In addition, much of the harvesting is in sawtimber sized stands, making rotations of 80 years or longer appropriate (Jones 1967). However, aspen may not be managed on rotations as long as those for conifers in the central Rocky Mountains., A base age of 80 years allows full stand development and is a good compromise between 50 years used for aspen in the Lake States and 100 years used for conifers in the Rockies.

Before developing the family of site index curves, the assumption that height-age curves for different site indexes are proportional to the shape of the guide curve was examined using the method described by Chapman and Meyer (1949). The assumption of proportional shape was supported by the lack of trends in a plot of the coefficient of variation of height over the average age for each group, and by unsuccessful attempts to find a significant relationship between the coefficient of variation and transformations of average group age. Height values for the site index curves then were computed by dividing the right side of the guide curve equation by the estimated value of (H − 4.5) at the base age on the guide curve and multiplying by (S − 4.5), where S is the site index value.

Results

The final height-age equation for various site indexes is

$$H=4.5+2.07151\,(S-4.5)\,(1-e^{-0.007719A})^{0.93972}$$

Site index curves developed from this equation are shown in figure 1. Table 2 shows the estimated height of dominant trees at breast height ages 20 to 140 years for site indexes 20 to 100 at base age 80 years.

To calculate expected site index from height and age measurements, the above equation can be solved algebraically for S, which gives

$$S=4.5+0.48274(H-4.5)\,(1-e^{-0.007719A})^{-0.93972}$$

This equation does not provide a least squares estimate of site index, but with a pocket calculator, is useful for calculating site index without interpolating in table 2 or from figure 1. Table 3 shows site index values calculated from this equation for breast height ages 20 to 140 years and dominant heights of 10 to 128 feet. Only four plots had an average greater than 140 years and are not shown in table 3.

Field Application

Aspen site index in the Rocky Mountains is estimated least accurately when stands are young, especially less than 30 years old. At ages of 50 or more years, estimates are much more reliable (Jones 1966, 1967). Extrapolation beyond average breast height age of 140 years should be avoided because of the lack of data for older stands.

Adjacent clones of aspen in the central Rocky Mountains may have very different height-age relationships even when growing on areas of apparent uniform site quality (Shepperd 1981). Clonal diversity should be considered when estimating site index for a stand composed of many clones. If clones of the same age have different heights within a stand area of apparent uniform site quality, the site index sample should be distributed to in-

Table 2.—Estimated total height (in feet) of dominant aspen trees.

Breast height age (years)	Site index class								
	20	30	40	50	60	70	80	90	100
20	9.7	13.0	16.3	19.7	23.0	26.3	29.7	33.0	36.3
30	11.8	16.5	21.2	25.9	30.6	35.3	40.1	44.8	49.5
40	13.7	19.7	25.7	31.6	37.6	43.5	49.5	55.5	61.4
50	15.5	22.6	29.7	36.8	43.9	51.0	58.1	65.2	72.3
60	17.1	25.3	33.4	41.6	49.7	57.9	66.0	74.2	82.4
70	18.6	27.7	36.9	46.0	55.1	64.2	73.3	82.4	91.5
80	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0
90	21.3	32.1	42.9	53.7	64.5	75.3	86.2	97.0	107.8
100	22.4	34.0	45.6	57.1	68.7	80.3	91.8	103.4	115.0
110	23.5	35.8	48.0	60.3	72.5	84.8	97.1	109.3	121.6
120	24.5	37.4	50.3	63.2	76.1	89.0	101.9	114.8	127.7
130	25.4	38.9	52.4	65.9	79.4	92.8	106.3	119.8	133.3
140	26.2	40.3	54.3	68.3	82.4	96.4	110.4	124.5	138.5

clude as many clones as possible. At least two and preferably three representative clones in the stand should be sampled (Zahner and Crawford 1965). Care should be taken to ensure that average genetic composition of the stand is being sampled.

For each sampled clone, total height and breast height age should be determined for at least three dominant trees, and site index should be estimated from average dominant height and breast height age. Site index for the stand then should be calculated by averaging the site index values for the sampled clones. If possible, the site index values of the clones should be weighted by the areas occupied by the clones when calculating the average stand site index. If the clone is multi-storied, dominant trees selected for site index determination should not be previously suppressed trees which were released after breakup of a former overstory. Such trees may seriously underestimate site index. If suitable non-suppressed understory trees are not available, adjacent clones should be sampled.

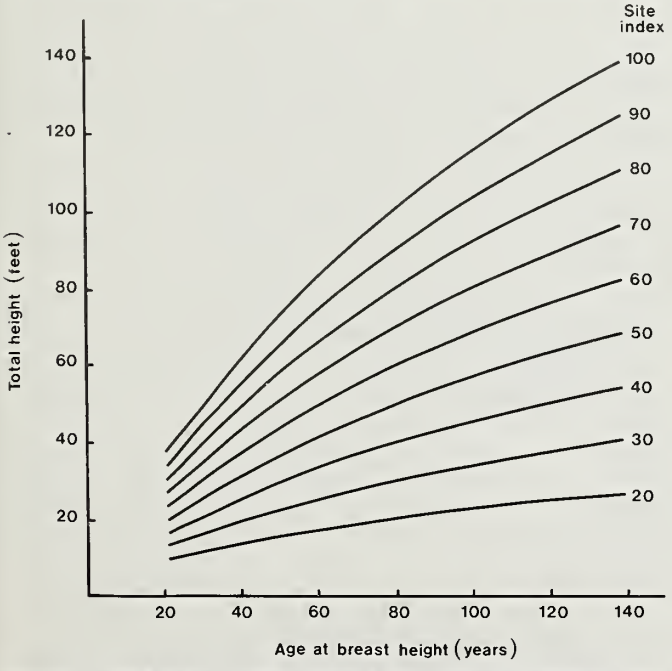

Figure 1.—Site index curves for aspen in Colorado, southern Wyoming, and northeastern Utah. Base age: 80 years, breast height.

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Table 3.—Site index of aspen[1] by height of dominant trees and age at breast height.

Height of dominant trees (feet)	Breast height age (years)																								
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140
10	21																								
12	27	23	20																						
14	33	28	25	22	20																				
16	39	33	**29**	26	24	22	21																		
18	**45**	**38**	33	30	27	25	24	**22**	21	20															
20	51	43	37	33	31	28	26	25	24	22	22	21													
22	**57**	48	42	37	34	31	29	27	26	25	24	23	22	21	21	20									
24	**63**	**53**	46	41	37	34	32	30	28	27	26	25	24	23	23	22	21	21	20						
26	**69**	58	50	45	**41**	37	35	**33**	**31**	**29**	28	27	**26**	**25**	24	24	23	23	22						
28	**75**	**63**	**54**	48	**44**	40	38	35	33	32	30	**29**	28	27	26	25	25	24	24						
30	81	**68**	**59**	52	**47**	43	40	38	36	34	32	**31**	30	**29**	28	27	27	26	25						
32	**87**	**73**	63	56	**51**	47	43	40	**38**	**36**	35	33	32	31	30	**29**	28	28	27						
34	**93**	**78**	67	**60**	54	**50**	46	43	41	**39**	**37**	**35**	34	33	32	31	30	29	29						
36	99	83	71	63	57	**53**	49	**46**	43	41	**39**	**37**	36	35	34	33	32	31	30	30					
38		**87**	**76**	67	**61**	**56**	52	48	46	43	41	40	38	37	**35**	34	33	33	32	31	30	30			
40		**92**	80	71	64	59	54	51	48	46	43	42	40	39	**37**	36	35	34	33	33	32	31	31	30	30
42		97	84	75	67	62	**57**	54	**51**	**48**	**46**	44	42	**41**	39	**38**	37	36	35	34	34	33	32	32	31
44		102	88	78	71	**65**	60	**56**	**53**	50	48	46	**44**	42	41	40	39	38	37	**36**	35	34	34	33	33
46			93	82	**74**	68	63	59	**55**	**53**	50	**48**	46	**44**	43	42	**40**	39	38	37	37	36	35	35	34
48			**97**	86	**77**	71	66	**61**	58	55	**52**	**50**	48	46	45	43	**42**	41	40	39	38	37	37	36	36
50			**101**	90	81	**74**	69	64	60	57	54	**52**	50	**48**	47	45	44	43	**42**	41	40	39	38	38	37
52				93	84	77	71	67	63	**59**	**57**	**54**	**52**	50	**48**	47	46	44	43	42	41	40	40	39	38
54				97	88	**80**	74	69	**65**	62	59	56	54	**52**	50	**49**	47	46	45	44	43	42	41	40	40
56				101	**91**	83	77	72	68	**64**	61	58	56	**54**	52	**50**	49	48	47	45	44	44	43	42	41
58					**94**	86	80	75	70	**66**	63	60	58	**56**	54	**52**	51	**49**	**48**	47	46	**45**	44	43	43
60					98	89	83	77	73	69	**65**	63	60	58	**56**	**54**	52	51	50	49	48	47	46	45	44
62					101	92	85	**80**	75	71	68	**65**	**62**	**60**	**58**	**56**	54	53	51	50	49	48	47	46	45
64						95	88	82	77	73	70	67	64	62	60	**58**	56	54	53	52	51	50	49	48	47
66						98	91	85	80	76	72	69	**66**	64	**61**	**59**	58	56	**55**	**53**	52	51	50	49	48
68						102	94	88	82	78	74	**71**	**68**	65	63	**61**	59	**58**	**56**	55	54	**53**	52	51	50
70							97	90	85	80	**76**	**73**	**70**	67	65	**63**	61	**59**	58	57	**55**	54	53	52	51
72							100	93	87	83	79	**75**	**72**	**69**	**67**	**65**	63	**61**	**60**	58	57	**56**	55	54	53
74							102	95	90	85	81	77	**74**	**71**	**69**	**67**	65	63	61	60	58	57	56	55	54
76								98	92	87	83	79	**76**	73	**71**	**68**	66	64	63	**61**	60	59	58	**56**	55
78								101	95	90	85	81	**78**	75	**72**	**70**	68	66	**64**	63	61	60	**59**	58	57
80									97	92	87	**83**	80	**77**	**74**	72	**70**	68	66	64	63	62	60	59	58
82									100	94	90	86	**82**	**79**	**76**	**74**	**72**	70	68	**66**	65	63	62	61	60
84									102	96	92	88	**84**	81	**78**	**75**	73	**71**	**69**	68	66	65	63	62	61
86										99	94	90	86	**83**	**80**	77	75	73	**71**	**69**	68	66	**65**	64	63
88										101	96	92	88	85	**82**	**79**	77	75	**73**	71	69	68	66	65	64
90											98	94	90	87	**84**	**81**	78	76	**74**	72	71	69	68	67	65
92											100	96	92	89	85	83	80	**78**	76	74	72	**71**	69	68	67
94											103	98	94	90	87	**84**	82	80	78	76	74	72	71	70	68
96												100	96	**92**	89	86	84	81	79	77	75	74	**72**	71	70
98												102	98	**94**	91	**88**	85	83	81	79	77	75	74	72	71
100													100	96	93	**90**	87	85	82	80	79	77	75	74	73
102													102	98	95	92	89	86	**84**	82	80	78	77	75	74
104														**100**	97	93	91	88	86	84	82	**80**	78	77	75
106														102	98	95	92	90	87	85	83	81	80	78	77
108															**100**	97	94	91	89	87	85	83	81	80	78
110																	96	93	91	88	86	84	83	81	80
112																	97	95	92	90	88	86	84	83	81
114																			94	92	89	87	86	84	83
116																			95	93	91	89	87	86	84
118																					93	90	89	87	85
120																					94	92	90	88	87
122																							92	90	88
124																							93	91	90
126																									91
128																									93

[1] *Values in bold indicate height-age observations.*